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TECHNICAL REPORT BRL-TR-2838

FORMATION OF HIGH AMPLITUDE PRESSURE WAVES IN A 5-In./54 LOVA CHARGE

LANG-MANN CHANG

SEPTEMBER 1987

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The ignition process occurring in the 5-inch, 54-caliber (5-in./54) LOVA (Lot 2163BL) charge was investigated via simulator diagnostics. The ignition system of the charge was the Mk 45 Mod 1 primer with Class 2 black powder as igniter material. This investigation was carried out to determine the cause of the high-amplitude pressure waves exhibited on the pressure-time curves recorded in gun firing tests. The results obtained also provided guidance for the development of an improved ignition system for the charge. The diagnostics proceeded with ignition of the primer in empty chambers, then in inert propellant packed chambers, and finally with live LOVA charges. The results from all of the experiments clearly indicate that localized venting of igniter gases from the primer was responsible for the occurrence of the pressure waves. The venting was so strong that it caused severe grain fracture not only in the region covered by the venting but also at the breech and the forward ends of the propellant bed. The grain fracture gave a sudden increase in burning surface area. This further enhanced the pressure waves generated by

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ABSTRACT (continued)

the vigorous combustion zone in the initial ignition site. Recommendations have been made to modify the primer and more testings are underway to optimize the ignition system for the 5-in./54 LOVA charge.

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I. INTRODUCTION

The current demand for increased weapon system survivability has focused attention on the use of insensitive propellants (LOVA) as a means of reducing system vulnerability. The U.S. Navy has made considerable effort in developing such propelling charges for the 5-in./54 gun system. In this development program, during gun firing tests two rounds with LOVA (Lot 2163BL) charges which had only small difference in charge weight (9.45 kg vs. 9.68 kg) showed a dramatic difference in their pressure data. Both rounds used the MK 45 Mod 1 primer. Figure 1 and Figure 2 present the pressure histories monitored at four locations along the gun barrel in the two rounds. The differential pressure dP ($=P_{464\text{-mm}} - P_{895\text{-mm}}$) was also shown, where $P_{464\text{-mm}}$ and $P_{895\text{-mm}}$ were the pressures monitored at 464 mm and 895 mm from the breech end, respectively. The peak pressure reached 310 MPa (45 kpsi) in the first round and 648 MPa (94 kpsi) in the second round. In addition, the pressure curves for the high pressure round exhibited several pressure steps before reaching their peak values. From the dP curve in Figure 2 it is apparent that high amplitude pressure waves formed and the waves traveled back and forth in the gun chamber before the projectile exited the barrel. Investigations to determine the cause of the inconsistent interior ballistic results and the

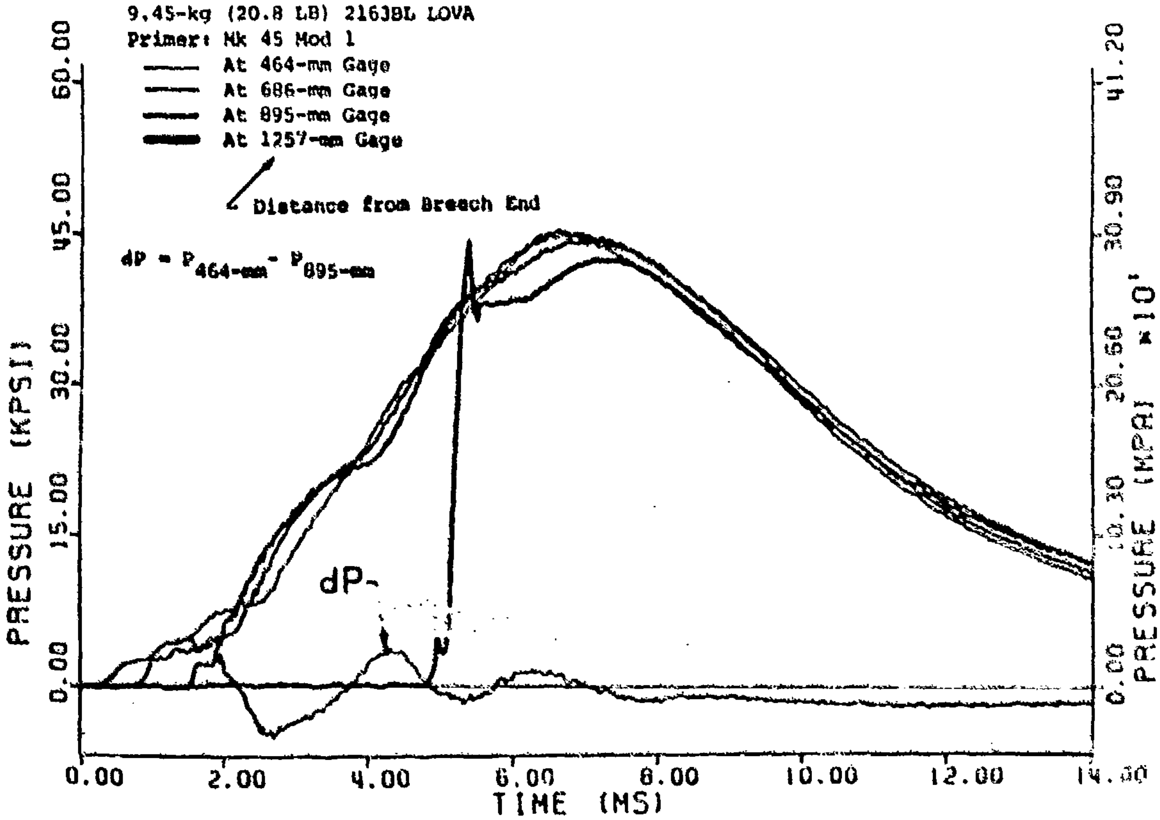

Figure 1. Pressure Data Recorded in Gun Firing Test (5-in./54 LOVA/2163BL Charge, Round No. 1)

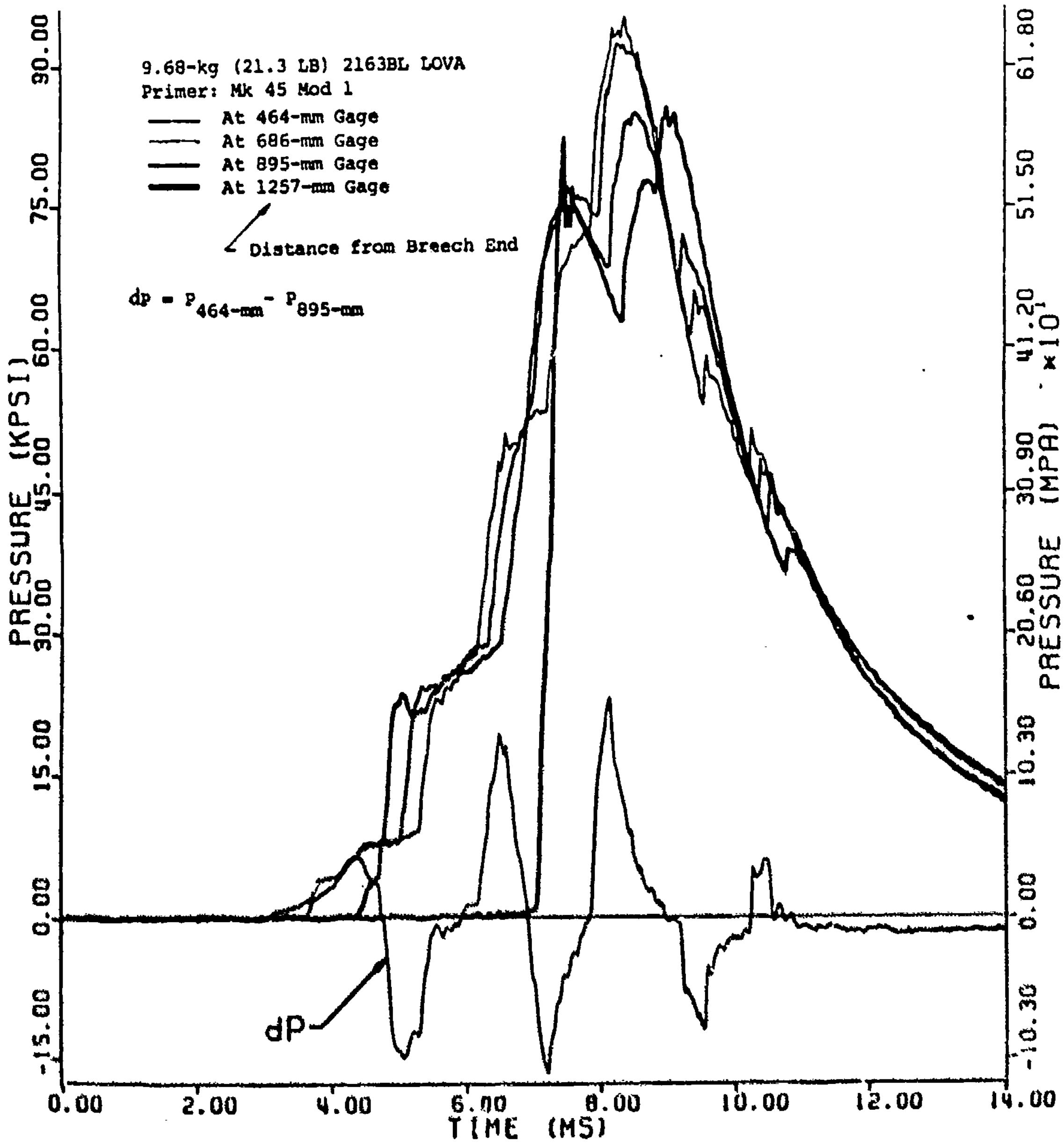

Figure 2. Pressure Data Recorded in Gun Firing Test (5-in./54 LOVA/2163BL Charge, Round No. 2)

unusual pressure behavior on these rounds were obviously necessary before conducting further gun firing tests with LOVA charges. With its experience in gun simulator diagnostics, the U.S. Army Ballistic Research Laboratory (BRL) was requested to join with the Navy Naval Ordnance Station at Indian Head, Maryland to pursue the investigation effort.

II. EXPERIMENTAL APPARATUS

Figure 3 shows a cutaway view of the gun simulator for the present study. The simulator chamber which was made from a transparent acrylic tube was adapted to a breech block at one end and to a short gun tube at the other end. The gun tube was cut from an actual 105-mm tank gun. The projectile had a flat base and would move when the chamber pressure rose to a certain level. There were no filler elements between the projectile base and the propellant bed. The simulator chamber had an inner geometry and dimensions close to that of the 5-in./54 gun chamber and was capable of withstanding pressures in excess of 15 MPa before it ruptured. Two 16-mm high-speed cameras (Photec) with a framing capability of 10,000 pictures per second were employed for recording the flamespread along the chamber length. Three piezoelectric pressure transducers (PCB model 113A23) were installed for monitoring the chamber pressure, two in the breech end and one in the projectile base. In addition, a linear displacement gage was attached to the forward end of the projectile to record the projectile motion. The firing control and data acquisition required were performed by using the Ballistic Data Acquisition System at Range 18 of the BRL.

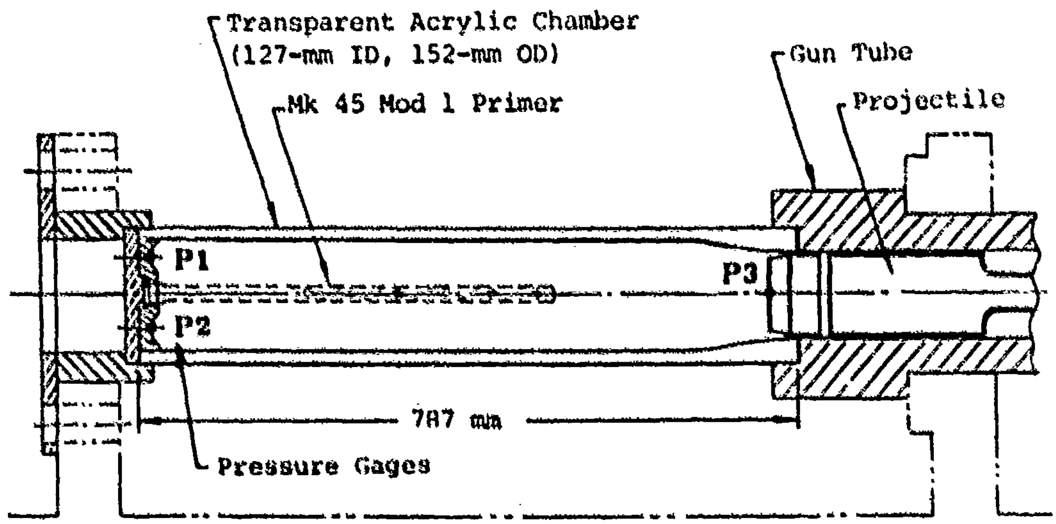

Figure 3. 5-in./54 Gun Simulator

III. RESULTS AND DISCUSSION

In this study, six rounds were fired with the simulator. The ignition system used throughout was the MK 45 Mod 1 primer loaded with 52 grams of Class 2 black powder. The test plan was as follow: two rounds with ignition of the primer in an empty chamber, two rounds with ignition of the primer in an inert propellant packed chamber, and the final two rounds with live LOVA (Lot 2163BL) propellant. This test arrangement allowed us to examine in detail the functioning of the ignition system, ignition of propellant,

pressure behavior, and dynamic bed rheology occurring during the early phase ballistic cycle. In the inert and live rounds, the chamber was fully filled without apparent ullage.

The following table presents a comparison of the dimensions and mechanical properties of the propellant grains used in the firings. The grain size of the inert propellant was slightly smaller than that of the live LOVA propellant. Both were seven-perforation cylindrical geometry.

As shown in Figure 4, the primer had a total length of 542 mm (21.35 inches) with an unvented section of 235 mm (9.25 inches) from its rear end. The forward end of the primer was sealed by a paper card board. The vented section was located near the central portion of the cartridge chamber. Thus if venting was uniformly distributed along the vented section, even flame-spreading toward the two ends of the propellant bed would result.

Dimensions and Mechanical Properties
of Inert and Live Propellant Grains

	LOVA/2163BL Grains	Inert Propellant Grains
Geometry	Cyl, 7P	Cyl, 7P
Grain Length (mm)	17.22	15.75
Grain Dia. (mm)	8.46	7.87
Dia. of Perf. (mm)	0.91	0.79
Web (mm)	1.44	1.38
Stress of Failure (MPa)	83.50	102.00
Strain of Failure (%)	3.0	4.7
Strain Rate ($second^{-1}$)	250.0	300.0
Modulus of Elasticity (GPa)	5.07	3.62

Note: The above mechanical properties were obtained from the test results of Robert Lieb of BRL.

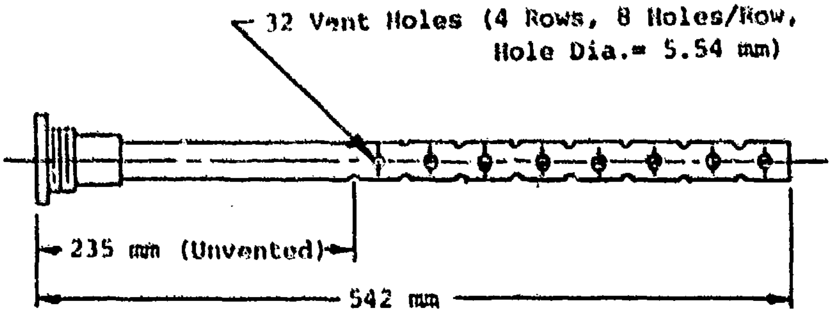

Figure 4. Schematic of Mk 45 Mod 1 Primer

A. Ignition of Primers in Empty Chambers

Two rounds were fired with a MK 45 Mod 1 primer ignited in an empty simulator chamber. The first round was designed for system checkout, and unfortunately no reliable data were obtained. The firing of the second round was successful. Figure 5 presents the pressure curve recorded by one of the two pressure gages installed in the breech end of the empty chamber. The time coordinate in the figure represents the time after application of the firing voltage. The early pressure rise was extremely steep and fluctuated in amplitude. Previous results in tank gun simulator tests with benite primers did not display such severe phenomena.[1,2] The steep pressure rise indicates that the venting of igniter gases started abruptly. The fluctuation of the curve was a result of the wave reflection between the two ends of the chamber. The time interval between two adjacent pressure peaks was 2.3 ms which was in the same magnitude of the time needed for a sound wave to travel from one end to the other end of the chamber.

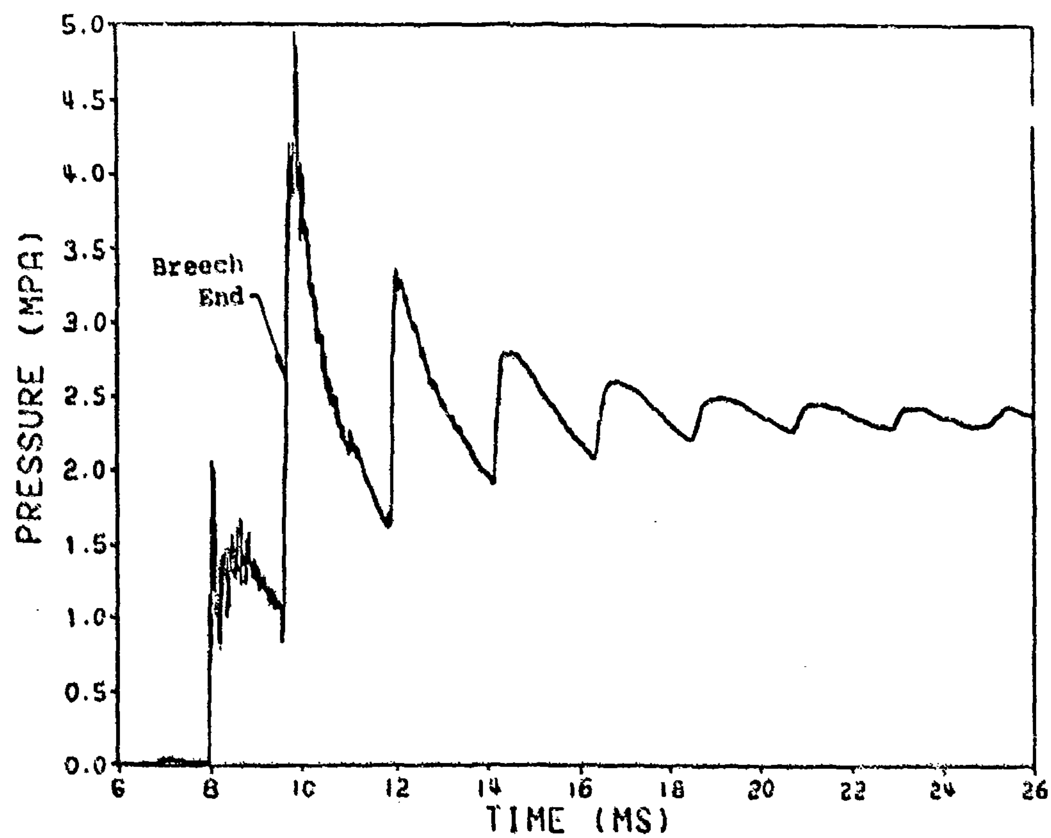

Figure 5. Pressure Data for Primer Ignition in an Empty Chamber

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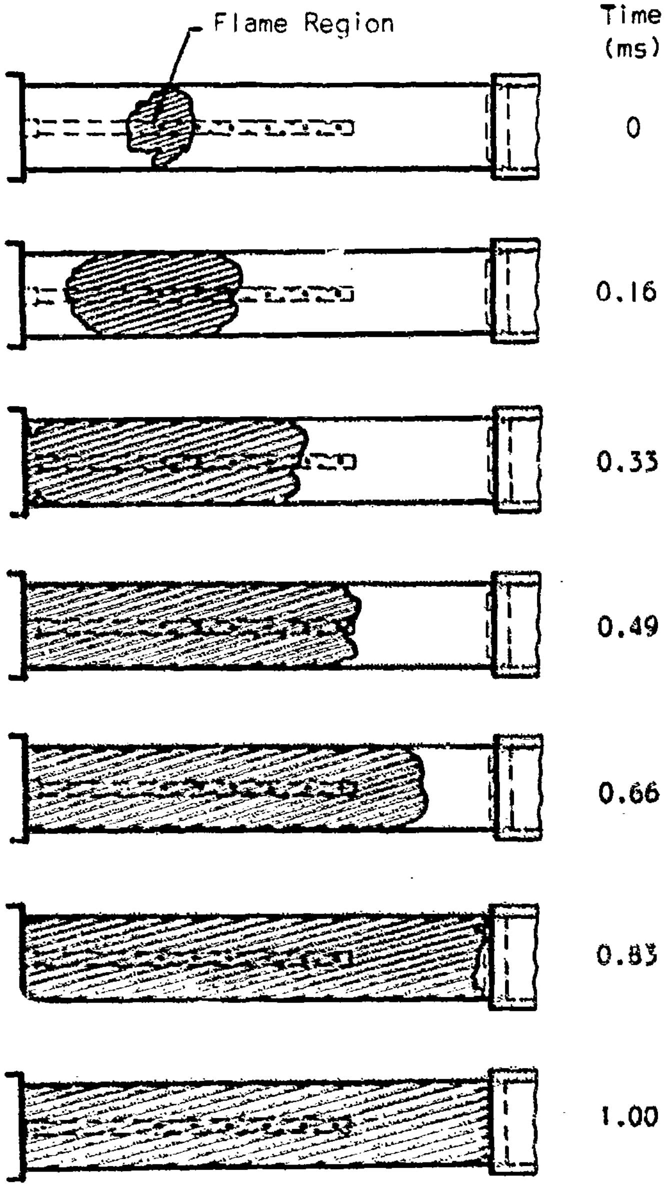
[1] L.M. Chang and J.J. Rocchio, "Early Phase Interior Ballistic Cycle Studies in a Tank Gun Simulator," Proceedings of the 8th International Symposium on Ballistics, pp. I-13 - I-24, Oct 1986.

[2] L.M. Chang, J. Grosh, and R.W. Deas, "Ignition Studies with Two-Piece Cartridges for the 120-mm Lightweight Gun System," Submitted for presentation at the 1987 JANNAF Propulsion Meeting, San Diego, CA, Dec 1987.

Furthermore, the mean value of the fluctuating pressure quickly reached the final maximum chamber pressure 2.25 MPa. This could mean that the majority of the energy in the primer was releas~d in a very short period of time.

Figure 6 shows schematics of the flamespreading occurring in the simulator chamber as observed on the high-speed film. In the figure the times are



The times are referenced to the instant that the flame was first seen.

Figure 6. Flamespreading for Primer Ignition in an Empty Chamber

referenced to the instant that the flame was first seen. The flamespreading initiated from the region where the first few vent holes closest to the rear end of the primer were located. During the flamespreading period, no significant venting was observed along the remaining section of the primer tube. In fact, the symmetry of the flamespreading toward the two ends of the chamber is also a strong indication that the venting was taking place only in a narrow segment of the chamber length. In addition, the film also shows that the flame fronts traveled back and forth between the chamber ends, concurrent with the fluctuation of the pressure curves in Figure 5. The visible flame endured more than 20 ms before it diminished.

B. Ignition of Primers in Inert Propellant Packed Chambers

While the previous firings with empty chambers allow us to observe the venting of igniter gases in detail, the firings with inert propellant packed chambers provide us another set of important information. This includes the intensity of venting, amount of propellant covered by igniter gases, dynamic rheology of the bed, and chamber pressure rise without ignition of propellant. Some of these data cannot be obtained in firings with live charges.

Although a pressure gage failure was encountered in the first of the two rounds fired, the high-speed film provided good photographic data of flamespreading. The first frame in Figure 7 shows that the venting of igniter gases initiated in the same location as observed in the case with the empty chamber. Post firing examination found that approximately 0.5 kg of grains in the strong venting region fractured to various degrees, some in the form of powder, see Figure 8. A number of fractured grains also appeared near the projectile base as well as at the breech end. Such grain fracture is expected to occur also in live LOVA charges since the above table shows that the mechanical properties of the inert propellant and the LOVA propellant fired were similar.

In the second round packed with inert propellant, the chamber ruptured. This is extremely unusual since the inert propellant did not burn and the pressure rise due to the ignition of the primer is normally far below the limit that the chamber can withstand (normally, greater than 10 MPa).[1,2,3] The cause of the rupture can be explained by examining the following pressure and photographic data.

Figure 9 exhibits the pressure rises at the breech and at the forward ends of the chamber. It is noted that the peaks of the pressures in the figure arrived immediately after the chamber ruptured. The curves show that the forward pressure rose very rapidly and overrode the breech pressure before the chamber ruptured. Apparently, there was severe localized pressurization taking placing near the forward end of the chamber. To determine the reason we have to examine the photographic evidence of the flamespreading.

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[3] L.M. Chang and J.J. Rocchio, "Simulator Diagnostics of Early Ignition Phenomena in a 120-mm Tank Gun Propelling Charge," Proceedings of the 9th International Symposium on Ballistics, pp. 1-90 - 1-102, Apr 1986.

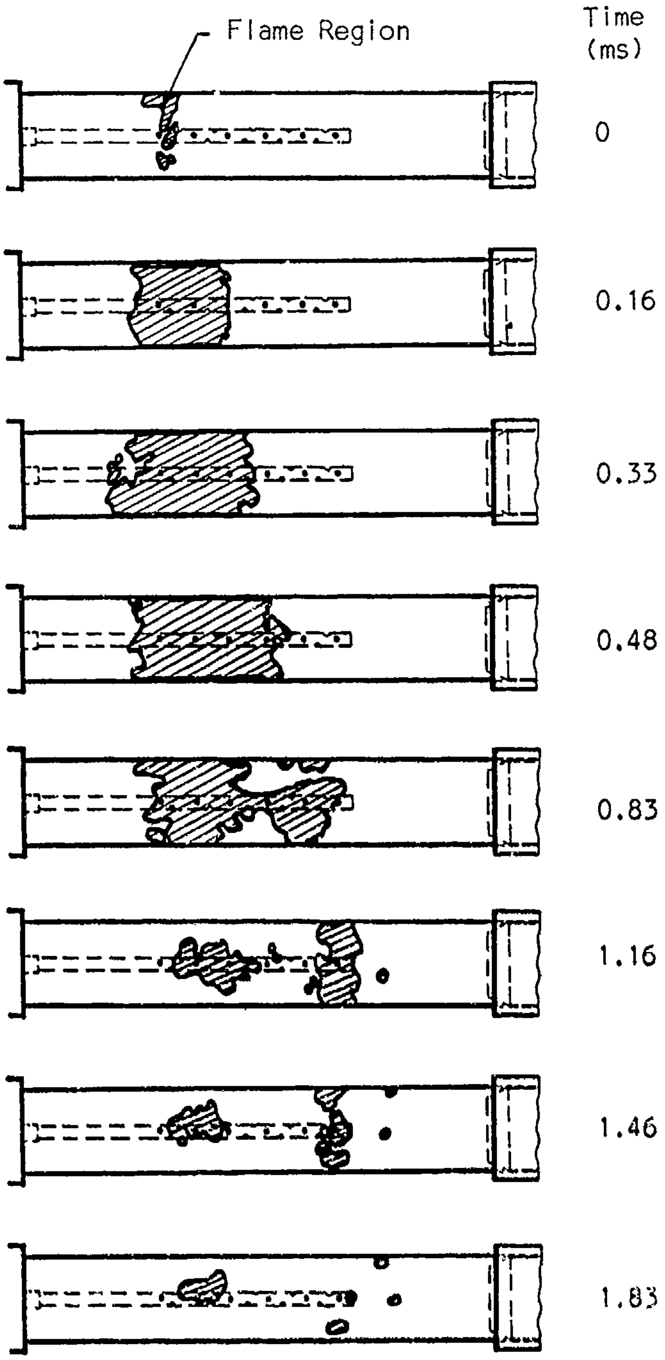

Figure 7. Flamespreading for Primer Ignition in the First Inert Propellant Packed Chamber

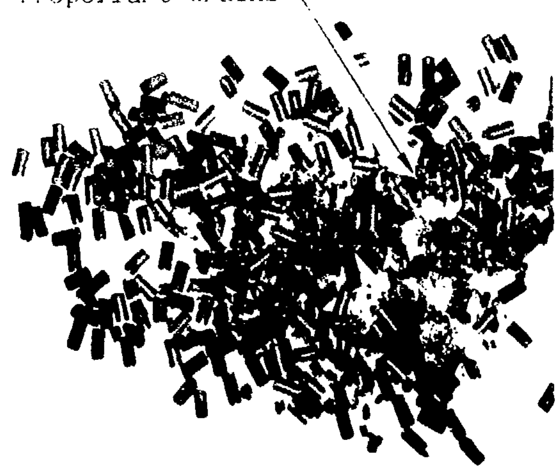

Figure 8. Fractured Inert Propellant Grains

Despite the failure of the first camera, the flamespreading recorded by the second camera, which viewed approximately two thirds of the chamber length from the breech end, still provides us sufficient information. Figure 10, directly traced from the high-speed film taken by the second camera, shows that the venting started in the region of the first two vent holes. Then a second flame appeared in the region where the forward end of the primer was located. We note that the forward end of the MK 45 Mod 1 primer is sealed by a paper plug only, which cannot hold a high pressure before being ejected. Thus we believe that in this round a large amount of the black powder came out the primer tube following the end plug and subsequently ignited. The ignition caused an abrupt local pressure rise which exceeded the strength limit of the chamber wall. The initiation of chamber rupture in front of the primer tube can be clearly identified on the high-speed film. Such an abnormal venting procedure also can induce pressure waves in gun firings.

C. Test Firings of Live Charges

In the two rounds fired with live charges, the pressure and photographic data obtained show good reproducibility, as seen when comparing Figure 11 with Figure 12 and comparing Figure 13 with Figure 14. We see that the breech pressure was much higher than the pressure at the forward end of the chamber. Furthermore, the peak pressure at the breech occurred substantially earlier (more than 0.6 ms) than at the forward end. The implication is clear that the pressure was extremely localized near the breech. Both Figures 13 and 14 indicate that the ignition started in the same region as observed in the inert beds and empty chambers presented earlier. In the same pattern, the flame spread symmetrically toward the two ends of the chamber. Before the flame front reached the projectile base, the chamber ruptured. The location where the rupture initiated is concurrent with the region where the pressure was the highest. After firing, a number of fractured grains (some in the form of powder) were found remaining in the gap between the projectile and the forcing cone of the gun barrel, as shown in Figure 15. Similar fractured grains were also seen at the breech end.

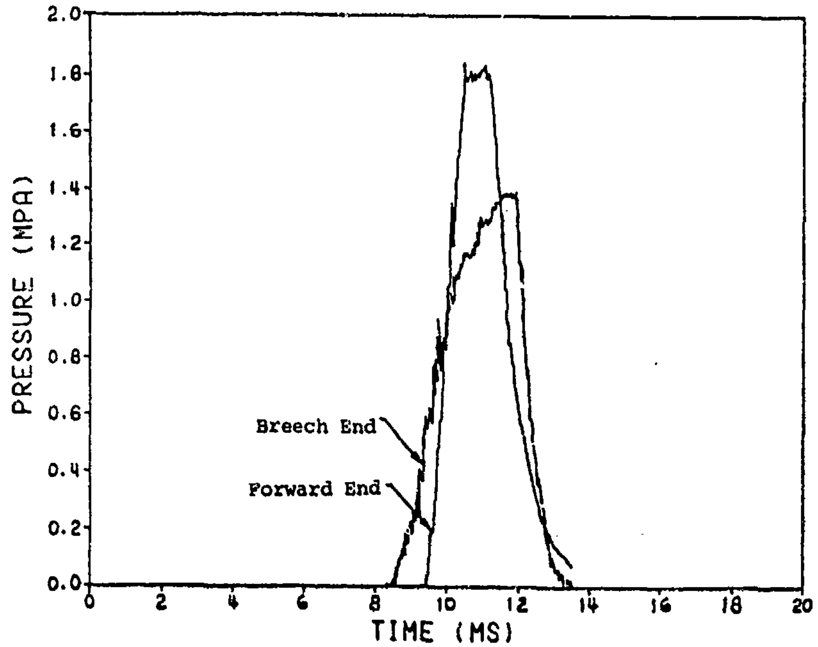

Figure 9. Pressure Data for Primer Ignition in the First Inert Propellant Packed Chamber

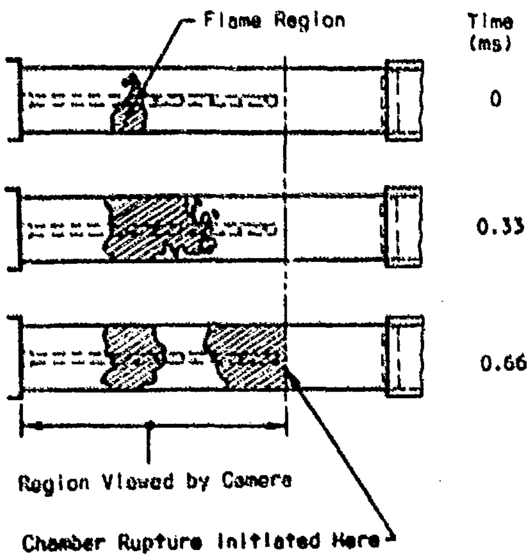

Figure 10. Flamespreading for Primer Ignition in the Second Inert Propellant Packed Chamber

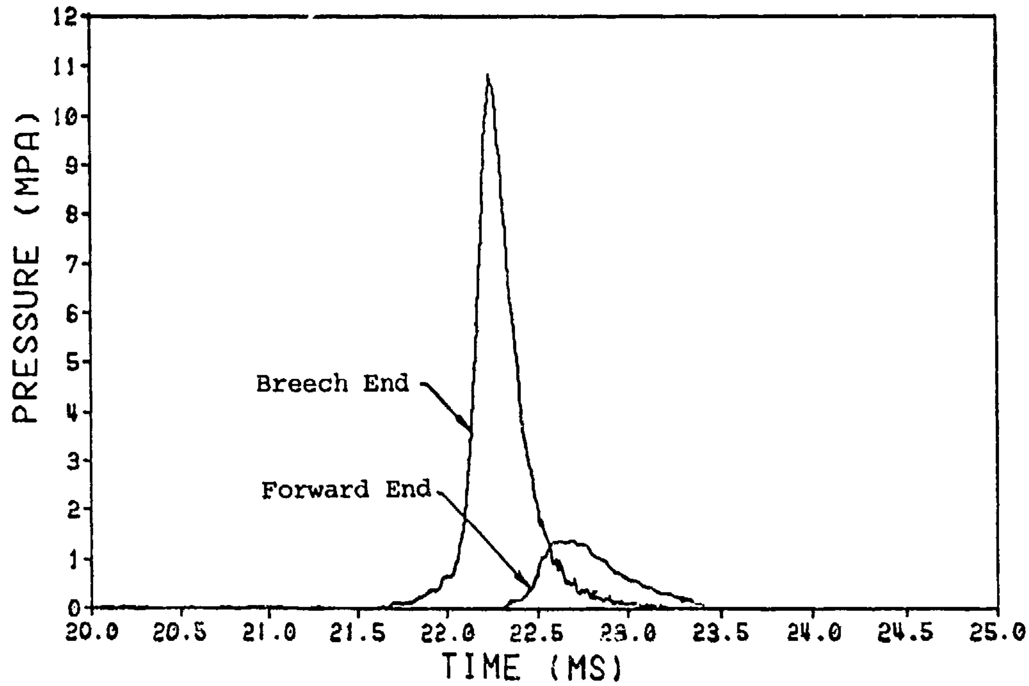

Figure 11. Pressure Data for the First Live Charge

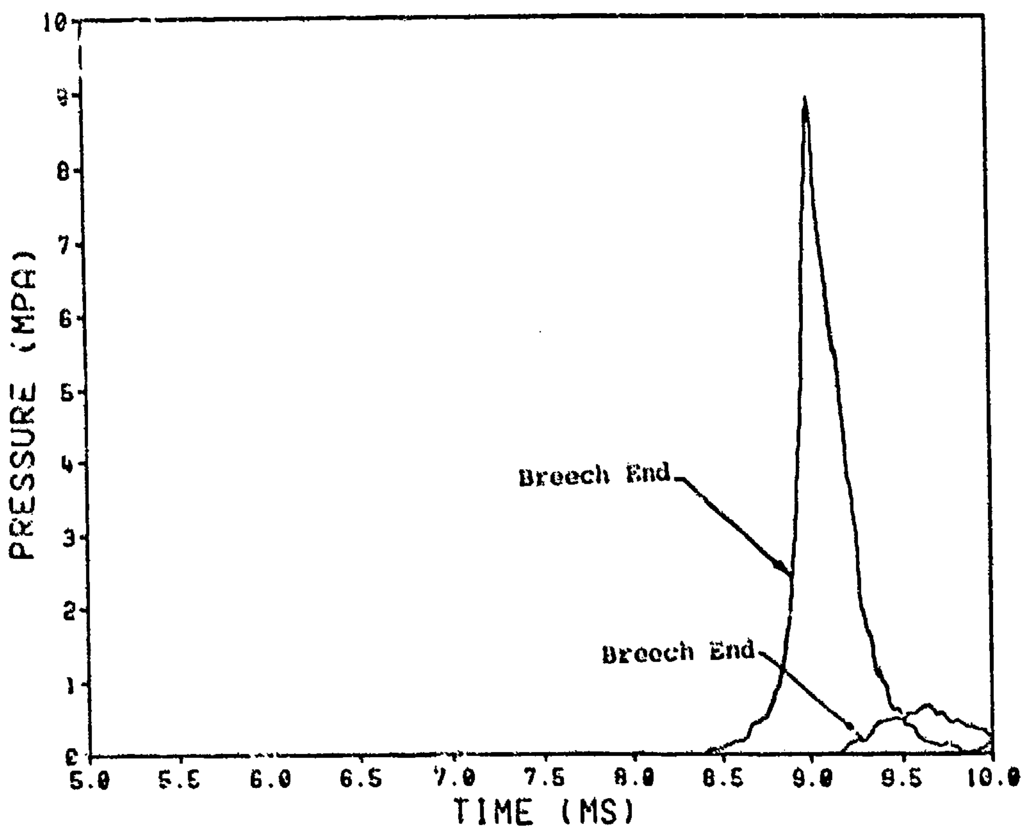

Figure 12. Pressure Data for the Second Live Charge

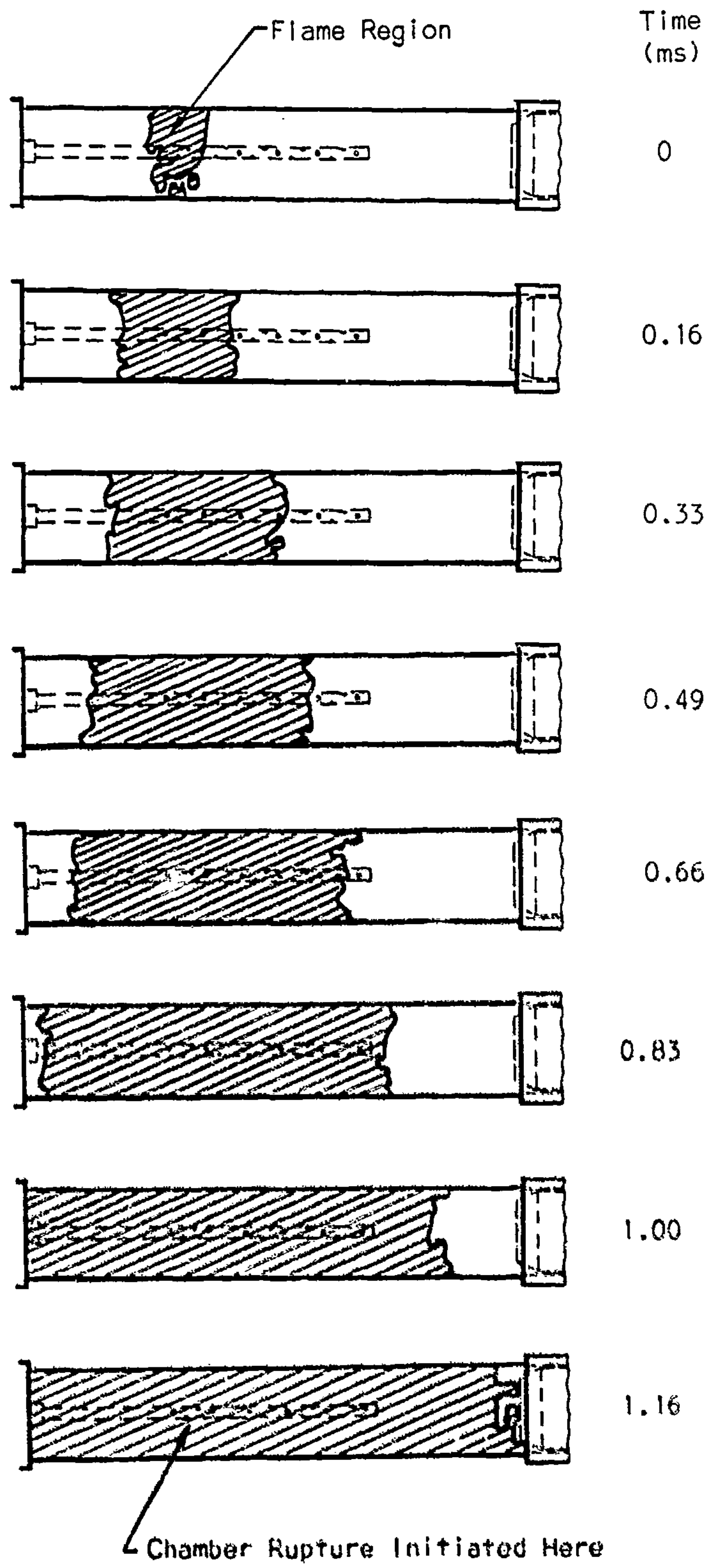

Figure 13. Flamespreading for the First Live Charge

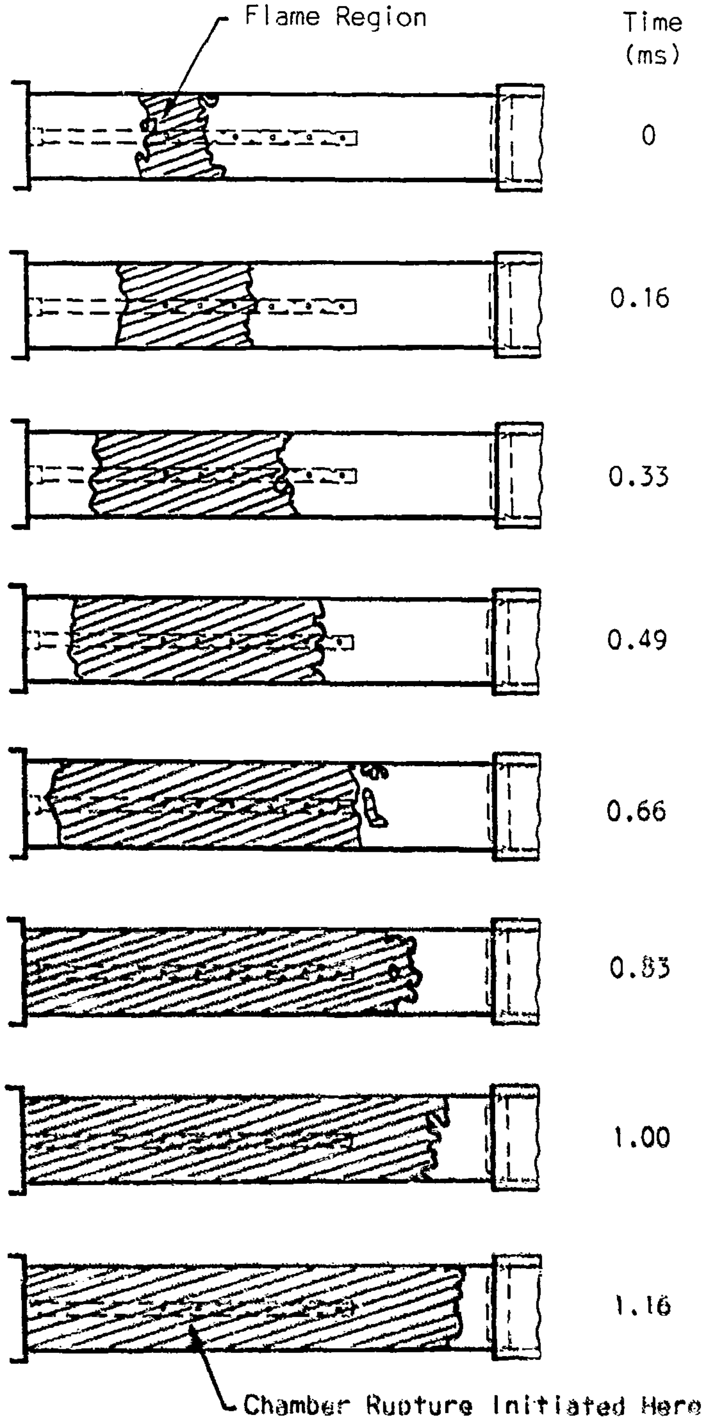

Figure 14. Flamespreading for the Second Live Charge

Figure 15. Fractured LOVA Propellant Grains

IV. SUMMARY AND CONCLUSIONS

Ignition studies were conducted systematically with ignition of the MK 45 Mod 1 primer in empty chambers, then in inert propellant packed chambers, and finally with live LOVA charges. The emphasis of the studies was on the flamespreading and pressure rise in the propelling charge.

The primer is designed to provide uniform ignition of propellant in the cartridge, i.e., simultaneous ignition along the primer tube length. However, the present test results show that the primer did not function this way. Photographic data clearly indicate that the venting at the rear section of the primer tube predominated. Such an uneven venting distribution will introduce localized ignition and thus is enough to induce pressure waves. This localized venting is likely due to the granular black powder igniter which provides very limited path for flamespreading along the length of the primer tube.

In one of the rounds fired with inert propellant, a second flame region was observed at the forward end of the primer. Post firing examination found that the forward plug was lost. Thus the second flame is believed to be created by the ignition of a large amount of black powder ejected from the primer end. The local pressure rise was so rapid and so high that it ruptured the simulator chamber, which rarely occurred in past firings when only a primer was used. The loss of the forward plug could account for great variability in ballistic performance in guns.

The output rate of the MK 45 Mod 1 primer was so large that grain fracture actually occurred in the venting area and at the forward end as well as at the breech end of the inert and live LOVA propellant beds. Bed compaction seems to be responsible for the fracture. The grain fracture would contribute to the magnitude of the pressure waves recorded in the gun firings.

Based on these results, we conclude that the occurrence of the high amplitude pressure waves and the great variability of the ballistic performance experienced in the gun firing tests were due to one or more of the following three factors:

1. Localized venting of the primer near the breech - inducing localized ignition of the LOVA propellant.
2. Output rate of the primer was too large - causing bed compaction and grain fracture.
3. Loss of the primer end plug - inducing localized ignition of the propellant in front of the primer tube.

V. RECOMMENDATIONS

Upon the completion of this test program, several recommendations were made to improve the performance of the ignition system. First, adopt benite strands as substitute of black powder as igniter material. Benite strands have satisfactorily been used in many kinds of bayonet-type primers for standard and LOVA charges for Army tank guns. It has long been recognized that the benite primer has a very favorable flow characteristic of low resistance to the transport of the hot gas generated in the booster to the forward end of the primer. Thus it can provide more uniform venting of igniter gases along the primer tube and consequently more uniform ignition of propellant in the gun chamber. Second, extend the length of the primer tube from 542 mm (21.3 inches) to 635 mm (25 inches) to cover almost full length of the propellant bed. Third, use a metal end plug to prevent the benite strands from coming out the tube. Forth, increase the number of vent holes and to reduce the hole diameter, while the total vent area on the primer tube in a given length remains the same. This is designed to initially ignite more propellant surrounding the primer and to maintain a high output rate of igniter gases for a longer period of time during the early venting process. The reasons have been explained more fully in Reference 4. Primers of this design have been demonstrated to be effective in ignition of LOVA propellants in tank gun systems.[4,5,6]

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[4]L.M. Chang, "Early Phase Ignition Phenomena Observed in a 105-mm Tank Gun Chamber," 21st JANNAF Combustion Meeting, CPIA publication 412, Vol. II, pp. 301-311, Oct 1984.

[5]L.M. Chang, K.P. Resnik, and J.J. Rocchio, "Ignition Studies for Charge Development for an Advanced 105-mm Kinetic Energy Cartridge," 23rd JANNAF Combustion Meeting, CPIA Publication 457, Vol. II, pp. 297-306, Oct 1986.

[6]Kevin P. Resnik, "Charge Development of High Energy Nitramine Composite Propellant (HELOVA) for an Advanced 105-mm Kinetic Energy Cartridge," 23rd JANNAF Combustion Meeting, CIPA Publication 457, Vol. II, pp. 319-327, Oct 1986.

Test firings with the improved primer designs have been conducted in the simulator. The results show great improvements in the uniformity of venting of igniter gases and the pressure distribution in the simulator chamber. Efforts are underway in the Navy to optimize the primer configuration and to select appropriate igniter material for the primer. Results will be reported as soon as the simulator tests for the new ignition systems are completed.

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5. L.M. Chang, K.P. Resnik, and J.J. Rocchio, "Ignition Studies for Charge Development for an Advanced 105-mm Kinetic Energy Cartridge," 23rd JANNAF Combustion Meeting, CIPA Publication 457, Vol. II, pp. 307-316, Oct 1986.

6. Kevin P. Resnik, "Charge Development of High Energy Nitramine Composite Propellant (HELOVA) for an Advanced 105-mm Kinetic Energy Cartridge," 23rd JANNAF Combustion Meeting, CPIA Publication 457, Vol. II, pp. 319-327, Oct 1986.

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